NASA

Technical Memorandum 80674

(NASA-TM-80674) SYNCHROTRON COOLING AND ANNIHILATION OF AN E(+)-E(-) PLASMA: THE RADIATION MECHANISM FOR THE MARCH 5, 1979 TRANSIENT (NASA) 21 p HC A02/MF A01 N80-26229
CSCL 03A G3/89 Unclas 22343

SYNCHROTRON COOLING AND ANNIHILATION OF AN e^+–e^- PLASMA: THE RADIATION MECHANISM FOR THE MARCH 5, 1979 TRANSIENT

R. Ramaty, R. E. Lingenfelter and R. W. Bussard

MARCH 1980

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

Synchrotron Cooling and Annihilation of an e^+-e^- Plasma: The Radiation Mechanism for the March 5, 1979 Transient*

R. Ramaty
Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771, USA

R. E. Lingenfelter
Physics Department and Center for Astrophysics and Space Sciences
University of California San Diego
La Jolla, California, 92093, USA

R. W. Bussard**
Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771, USA

*Invited Paper presented at the Toulouse Conference on Gamma Ray Bursts, Toulouse, France, November 1979. Conference Proceedings to be published in Astrophysics and Space Science

**Present Address: Physics Department, University of Illinois, Urbana, IL 61801, USA

Abstract

Positron-electron pair radiation is examined as a mechanism that could be responsible for the impulsive phase emission of the March 5, 1979 transient. Synchrotron cooling and subsequent annihilation of the pairs can account for the energy spectrum, the very high brightness, and the ~ 0.4 MeV feature observed from this transient, whose source is likely to be a neutron star in the supernova remnant N49 in the Large Magellanic Cloud. In this model, the observed radiation is produced in the skin layer of a hot, radiation-dominated pair atmosphere, probably confined to the vicinity of the neutron star by a strong magnetic field. The width of this layer is only about 0.1mm. In this layer, $\sim 10^{12}$ generations of pairs are formed (by photon-photon collisions), cooled and annihilated during the ~ 0.15 sec duration of the impulsive phase. The very large burst energy implied by the distance of the LMC, and its very rapid release, are unsolved problems. We mention, nonetheless, the possibility of neutron star vibrations, which could transport the energy coherently to the surface, heat the atmosphere mechanically to a hot, pair-producing temperature, and have a characteristic damping time roughly equal to the duration of the impulsive phase.

I. Introduction

Gamma ray lines have recently been detected from at least two gamma-ray bursts. Line emission identified as redshifted 0.511 MeV positron annihilation radiation was seen in the March 5, 1979 event (Mazets et al., 1979; Mazets and Golenetskii, 1979), and two lines, one identified as redshifted 0.511 MeV emission and the other as redshifted 0.847 MeV Fe^{56} deexcitation radiation, were seen in the November 19, 1978 burst (Teegarden and Cline, 1980). The redshifted 0.511 MeV feature in the November 19, 1978 burst was also seen by Mazets and Golenetskii (1979). These observations have important implications for the origins of gamma ray transients. In this paper we shall focus on the March 5, 1979 transient, because of the special problems and interesting physics associated with the probable identification of the source of this outburst with a neutron star in a supernova remnant in the Large Magellanic Cloud (Evans et al., 1980). In another paper, Teegarden and Cline (1980) discuss some of the implications of their observation of redshifted line emission in the November 19, 1978 burst.

Cosmic gamma ray line emission has also been observed from a variety of other sources: solar flares (Chupp et al., 1973; Hudson et al., 1980), the galactic center region (Leventhal, MacCallum and Stang, 1978), and possibly from an as-yet-undefined class of transient phenomena (Jacobson et al., 1978). These observations, and their theoretical interpretations, have recently been reviewed in considerable detail (Lingenfelter, Higdon and Ramaty, 1978; Ramaty and Lingenfelter, 1979; Ramaty, Kozlovsky and Lingenfelter, 1979; Vedrenne, 1980).

The March 5 transient was observed by instruments on 9 different spacecraft which form an interplanetary burst network (Mazets et al., 1979; Barat et al., 1979; Cline et al., 1980; Evans et al., 1980; see also Cline, 1980 for a review). The position of the burst, determined by this network to an accuracy of an arc minute, coincides with the supernova remnant N49 in the LMC. This is the first identification of a gamma ray transient with any known astronomical object.

The March 5 transient has several unique characteristics that set it apart from the general class of gamma ray bursts:

The peak flux of $\sim 10^{-3}$ erg/cm^{2}sec above 0.03 MeV (Mazets and Golenetskii, 1979), was an order of magnitude greater than that of any other gamma ray burst. At the distance of the LMC (55 kpc) this intensity implies a luminosity of $\sim 3\times10^{44}$ erg/sec.

The exceedingly short rise time of this impulsive phase, $< 2\times10^{-4}$ sec (Cline et al., 1980), suggests that the size of the emission region does not exceed $\sim$ 75 km, the light travel distance for this time. This requires that the source be a compact object.

The duration of the impulsive phase, $\sim$ .15 sec (Cline et al., 1980) was also much shorter than that of typical gamma ray bursts which last for several seconds. The energy fluence in the impulsive phase was $\sim 2\times10^{-4}$ erg/cm^2 (Mazets and Golenetskii, 1979) which at the distance of the LMC gives an impulsive energy release of $\sim 7\times10^{43}$ erg.

The impulsive phase was followed for at least three minutes by much less intense pulsed emission with a period of 8.0 $\pm$0.05 sec (Cline et al., 1980). The average pulsed flux of $\sim 10^{-5}$ erg/cm^2 sec decreased exponentially with characteristic time of $\sim$ 50 sec (Cline et al., 1980), so that the fluence in the pulsed phase was about twice that in the impulsive phase. The existence of these pulses suggest emission from the polar caps of a rotating neutron star.

In addition, the March 5 transient was followed by three other outbursts, apparently from the same source direction, on March 6, on April 4, and on April 24. The peak intensities of these outbursts, however, were much lower than that of the March 5 event, and decreased with each burst (Mazets and Golenetskii, 1979).

Finally, the energy spectrum of the March 5 transient was also quite different from that of other bursts. Mazets et al. (1979) have measured the spectrum for the first 4 seconds, an interval dominated by the impulsive phase, and for the subsequent

28 seconds of pulsed emission. The measured spectrum of the first 4 seconds is shown in Figure 1. The low energy ($\leqslant$ 0.3 MeV) part of this spectrum could be fitted by an exponential with a characteristic energy of 0.03 MeV. Above $\sim$ 0.3 MeV, however, the burst spectrum hardens, showing a broad spectral feature peaked at about 0.4 MeV. This feature could be gravitationally redshifted 0.511 MeV annihilation radiation produced close to the surface of a $\sim 1M_\odot$ neutron star with a surface redshift $z \simeq 0.28$.

The gravitational redshift, together with the rapid rise, the 8 sec pulsation, the pulse structure, and the association with a supernova remnant strongly suggest that the source of the March 5 transient was indeed a neutron star.

Despite the fact that the burst source position coincides with that of the supernova remnant N49, there are several apparent problems, if the source is located in the LMC. These concern the origin and rapid release of the very large amount of energy emitted in the transient, and the very high efficiency of the radiation mechanism. The required mechanism appears to violate the black-body limit in that it must provide a luminosity of several times 10^{44} ergs/sec at relatively low photon energies (tens of keV) from a small emitting area (a neutron star surface). Indeed, several authors (Mazets et al., 1979; Helfand and Long, 1979; Aharonian and Ozernoy, 1979; Petschek and Colvin, 1980) have argued that the source cannot be in the LMC. Mazets et al. (1979), assuming that the emission results from accretion on a neutron star, argue that the Eddington limit on the luminosity requires that the source must be closer than $\sim$ 300 pc. Aharonian and Ozernoy (1979) applying Shapiro and Salpeter's (1975) spherical accretion model, concluded that the source was most likely only 5 to 20 pc away. Helfand and Long (1979) argue that if the continuum radiation is due to thermal bremsstrahlung and the feature at $\sim$ 0.4 MeV is due to e^+-e^- annihilation, then for the emission region to be optically thin to the annihilation radiation the source would have to lie within 1 pc. But even if these are not the relevant energy sources or emission mechanisms, Aharonian and Ozernoy

(1979) also argue that the observation of MeV gamma rays in the burst limits its distance to less than 200 pc, because of the opacity of the source due to e^+-e^- pair production. This argument is essentially the same as that of Cavallo and Rees (1978) and Schmidt (1978) for bursts in general. In addition to difficulties with accretion models, Petschek and Colvin (1980) point out that even for sources internal to the star, the energy could not diffuse to the star's surface in a short enough time.

In the present paper we do take the point of view that the source of the March 5 transient is in the LMC, based on the rather convincing positional identification of the burst direction with N49. We find that the arguments against an LMC origin based on radiation mechanisms are all removed in our e^+-e^- synchrotron cooling and annihilation model. Regarding the energy source, its very large magnitude requires that it be interior to the star, most likely of gravitational origin. The release of this energy clearly cannot be by photon diffusion. An interesting, although as-yet not well researched possibility for the March 5 transient, is neutron star vibration which could, in a coherent and rapid fashion, communicate the internal energy to the upper crust and atmosphere. Decay of these vibrations by gravitational radiation could, in fact, account for the duration of the impulsive phase (D. Kazanas and P. Meszaros, private communication 1980).

In the present paper, however, we shall deal mostly with the radiation mechanism. In Section II, we provide a qualitative description of the model, while Section III provides a quantitative discussion of the radiating layer; for we find that essentially all the observed emission should be produced in a thin layer of unit optical depth in which synchrotron cooling of e^+-e^- pairs converts hot ($\sim$ MeV) radiation from the lower lying optically thick regions into the observed emission. We summarize our discussion in Section IV where we also discuss some additional difficulties and problems of the model.

II. Qualitative Description of the Model

A variety of sources of energy for gamma ray bursts from neutron stars have been proposed (see review by Ruderman 1975), but most of these appear to have insufficient energy to account for the March 5 transient at the distance of the LMC. It is beyond the scope of the present paper to discuss in detail possible energy sources for this transient. We merely mention the possibility (S. Bonazzola, private communication 1980) of a phase transition in the neutron star interior (e.g. Hartle, Sawyer and Scalapino, 1975) which could release an amount of gravitational energy that is a significant fraction of the neutron star's binding energy. As mentioned above, the energy could be stored in neutron star vibration (period 10^{-4} to 10^{-3} sec) whose dissipation by gravitational radiation (Thorne, 1969; Detweiler, 1975) could account for the $\sim$ 0.15 sec decay time of the impulsive phase (D. Kazanas and P. Meszaros, private communication 1980). In such a scenario, mechanical energy can be deposited in the upper layers of the neutron star crust and atmosphere leading to hot radiation capable of producing positron-electron pairs. As we shall see below, cooling and annihilation of such pairs should be responsible for essentially all the gamma-ray and hard x-ray emission of the transient without encountering the difficulties pointed out in the Introduction.

Regarding the radiation mechanism, the most obvious difficulty appears to be that, while on the one hand, to account for the observed bolometric luminosity ($L \simeq 3\times10^{44}$ erg/sec) a temperature $kT > 0.06$ MeV is required (at this kT a neutron star of 15km radius could emit blackbody radiation at the required L), on the other, the low energy part of the observed spectrum (< 0.3 MeV, see Figure 1) would only be consistent with black body emission if kT were less that about 0.03 MeV. Moreover this temperature would be too low to account for the high energy part of the spectrum, and it would also be too low to produce the e^+-e^- pairs that appear to be responsible for the 0.4 MeV feature. The pairs might be produced in a separate spatial region of higher temperature ($kT \geqslant mc^2$), but in this case their

annihilation emission would be inconsistent with the data, because its width would greatly exceed the observed width (< 0.3 MeV).

In the model that we propose, synchrotron cooling of hot (initially ~ MeV) positron-electron pairs and their subsequent annihilation are responsible for the entire observed spectrum of the impulsive phase. Hot radiation, possibly resulting from mechanical heating due to neutron star vibrations, produces e^+-e^- pairs. In the absence of cooling, such pairs annihilate to produce new photons of the same temperature, which in turn produce new pairs and so on. However, in the presence of a strong magnetic field, synchrotron cooling can be faster than annihilation. As we shall see below, for this to occur, B has to be about 10^{11} gauss. Since in such a magnetic field electrons and positrons of MeV energies produce radiation of tens of keV, the cooling effectively transforms the hot pair-producing radiation into cooler radiation devoid of pairs. This transition must take place in a layer whose thickness does not exceed the photon-photon pair production mean free path, because the annihilation radiation from the pairs that have already cooled cannot produce new pairs. Since the Compton cross section at energies from tens of keV to an MeV is comparable to the maximum $\gamma\gamma$ pair production cross section, and since (see below) synchrotron selfabsorption begins to affect the spectrum only below ~ 0.03 MeV, the opacity of the transition layer is about unity, and hence essentially all the observed radiation should originate in this layer. More specifically, the pairs produced in the transition layer by hot photons attempting to emerge from lower lying levels produce the low energy ($\lesssim$ 0.3 MeV) part of the observed spectrum by synchrotron radiation. Having lost the bulk of their initial kinetic energy by synchrotron cooling, the pairs establish an equilibrium temperature ($\lesssim$ 0.1 MeV) where the energy loss to the magnetic field is balanced by Comptonization. Annihilation at this temperature produces the high energy part of the spectrum.

This process of synchrotron cooling and subsequent annihilation of e^+-e^- pairs

overcomes the apparent difficulties of the radiation mechanism as follows:

Since the energies of the radiating particles (positrons and electrons of MeV energies) are high, this mechanism can produce the observed luminosity by emitting at a rate well below the black-body limit. The radiation intensity in the transition layer is in fact much lower than the black body value for MeV temperatures, thereby allowing the nonequilibrium cooling which is an essential ingredient of the model.

The shape of the low energy part of the spectrum is not representative of the temperature of the radiation. Rather, it is synchrotron radiation of much higher energy positrons and electrons produced in the transition layer by hot radiation from lower levels. The photons from these levels do not contribute significantly to the observed spectrum because they are absorbed in the transition layer.

The high temperature ($\sim$ MeV) just below the transition layer is entirely sufficient to produce copious numbers of e^+-e^- pairs. But the Doppler broadening of the annihilation feature is greatly reduced because the pairs are cooled before they annihilate. This cooling, of course, produces the low energy radiation which constitutes the bulk of the observed luminosity.

The model also overcomes the other difficulties that have been mentioned by previous authors. Obviously, synchrotron radiation in a strong magnetic field can be a much more efficient radiation mechanism than bremsstrahlung. Regarding the $\gamma\gamma$ opacity, photon-photon pair production would render the source opaque to high energy photons (greater than several MeV), since these would interact with the hard x rays above the transition layer. But there is not much evidence in the data for photons above $\sim$ 1 MeV (Mazets et al. 1979), and we would, in fact, not expect such photons if the source of the March 5 transient is in the LMC.

III. Parameters of the Transition Layer

The transition layer, which in our model produces essentially all of the observed radiation, should be strongly radiation dominated, i.e. the density of pairs produced by photon-photon collisions in the layer should greatly exceed that of the ambient matter there. Because ambient matter at an MeV has a large scale height ($\sim 10^4$cm for H around a $1M_\odot$ neutron star) its density must be relatively low ($\lesssim 10^{20}$cm^{-3}) in order that the region be transparent. Where it not for synchrotron cooling and annihilation, an e^+-e^- plasma would have an even larger scale height at this temperature. But the density of the pairs should in fact drop abruptly at the transition layer because there is almost no further pair production above it. As we shall see below, the width of this layer is only a fraction of a mm leading to a pair density in the layer of about 2×10^{26}cm^{-3}. We have obtained these estimates as follows:

The annihilation of e^+-e^- pairs in the transition layer produces the high energy ($\gtrsim 0.3$ MeV) part of the observed impulsive phase. The densities n_+ and n_- should therefore satisfy

$$\alpha n^2 \Delta h (r/d)^2 = F_a, \tag{1}$$

where $n \simeq n_+ \simeq n_-$, α is the annihilation rate coefficient, Δh is the thickness of the layer, and $F_a \simeq 250$ photons/cm^{2}sec is the observed photon flux above 0.3 MeV in the impulsive phase attributed to annihilation radiation. At relativistic temperatures α is temperature dependent. But since the pair temperature just before annihilation should not exceed about 0.1 MeV (otherwise the width of the feature would exceed that observed), α is essentially constant, $\alpha \simeq 7.5\times10^{-15}$cm^{2}sec (e.g. Bussard, Ramaty and Drachman 1979). Since Compton scattering should not smear out the line, the thickness of the layer should be about $(2n\sigma_c)^{-1}$, where in the energy range of interest σ_c is about 3×10^{-25}cm^2. For a neutron star radius $r = 1.5\times10^6$cm and $d = 55$ kpc, eq. (1) yields $n \simeq 2.5\times10^{26}$cm^{-3} and $\Delta h \simeq 10^{-2}$cm.

The initial kinetic energy of the pairs, $\gamma_o mc^2$, as they are produced in the transition layer, can be estimated from the data of Figure 1. Since in our model the low energy part of the observed energy flux density ($E \leqslant 0.3$ MeV) is due to the loss of this kinetic energy, we should have, approximately,

$$mc^2 (\gamma_o - 1) \sim (F_a)^{-1} \int_{0.03 \text{ MeV}}^{0.3 \text{ MeV}} dE\, E\, F(E). \tag{2}$$

The data of Figure 1 then yields $\gamma_o \sim 7$. An initial particle energy of about 3 MeV indicates that the radiation just below the transition layer should have a temperature of this magnitude. The density of this radiation, however, is much lower than the black body density at MeV energies. This can be seen by comparing the pair density deduced above ($\sim 2.5\text{x}10^{26} \text{cm}^3$) with the equilibrium pair density at such temperatures (e.g. Landau and Lifshitz, 1958) which turns out to be about 5 orders of magnitude higher. For this reason, rapid cooling in the outermost layer, for example by synchrotron radiation, should be possible.

The magnetic field B in the layer is estimated to be about 10^{11} gauss from the requirement that electrons and positrons with $\gamma \sim 7$ produce synchrotron emission with photon energies characteristic of the low energy part of the observed spectrum. To cool the pairs from an initial $\gamma_o \sim 7$ to $\gamma \leqslant 1.2$ ($kT < 0.1$ MeV), the synchrotron loss time, $t_s \sim \int_{\gamma}^{\gamma_o} d\gamma/(d\gamma/dt)_s$, must be shorter than the annihilation time, $t_a \sim (\sigma n)^{-1}$. In the case of strong pitch angle scattering (which we assume but which can also be expected in view of the very strong turbulence that accompanies the vibrational heating),

$$\left(\frac{d\gamma}{dt}\right)_s \sim 2\text{x}10^{-9}\, B^2(\gamma^2-1) \;(\text{sec}^{-1}). \tag{3}$$

With the above values of γ_o, γ and B, eq. (3) yields $t_s \sim 5\text{x}10^{-14}$ sec which is about an order of magnitude shorter than t_a for $n \sim 2.5\text{x}10^{26}$ cm^{-3}. Thus, the pairs could indeed annihilate after losing the bulk of their kinetic energy.

The synchrotron photon flux density produced by the cooling electrons and positrons in the transition layer can be evaluated from

$$F_s(E) \approx F_a\, E^{-1} \int^{\gamma_o} d\gamma\; p(E,\gamma)/(d\gamma/dt)_{eff}, \tag{4}$$

where $(d\gamma/dt)_{eff}$ is the effective energy loss rate of the particles (synchrotron loss minus possible energy gains), and $p(E,\gamma)$ is the synchrotron emissivity per particle per unit photon energy (e.g. Ginzburg and Syrovatskii, 1964). Eq. (4) is insensitive to the lower limit of the integration since most the synchrotron emission is produced by pairs close to their initial energy. Possible energy gain mechanisms that could affect $(d\gamma/dt)_{eff}$ are synchrotron selfabsorption and Comptonization.

We have evaluated the selfabsorption opacity for the present parameters, and we find that the transition layer becomes opaque at photon energies below about 0.025 MeV. From eq. (4) we also find that if $(d\gamma/dt)_{eff} = (d\gamma/dt)_s$, about half the synchrotron energy loss is in photons below 0.025 MeV. Therefore, a significant fraction of this energy is reabsorbed, and this amounts to an effective energy gain for the particles. This effect can be taken into account in an approximate manner by setting $(d\gamma/dt)_{eff}$ equal to about half $(d\gamma/dt)_s$, where the latter is given by eq. (3).

Comptonization of the pairs is caused by the hot ($\sim$ 3 MeV) photons which also produce the pairs in the layer. The heating rate by these photons is approximately given by

$$\left(\frac{d\gamma}{dt}\right)_c \approx \frac{L}{4\pi r^2}\, \sigma_c\, (mc^2)^{-1}, \tag{5}$$

where $L \approx 3\times10^{44}$ erg/sec is the luminosity of the impulsive phase. For the present parameters, $(d\gamma/dt)_c$ is much less than the synchrotron loss rate at MeV energies, approximately equals $0.5\,(d\gamma/dt)_s$ for $\gamma \approx 1.2$, and exceeds it at lower energies. The equilibrium temperature, kT, of the pairs in the layer should therefore be of the order 0.1 MeV. But since eq. (4) is sensitive mostly to

higher pair energies, Comptonization has essentially no effect on $(d\gamma/dt)_{eff}$ as applied to eq. (4).

The solid curve in Figure 1 has been calculated from the expression

$$F(E) = (1+z)\{F_s(E') + F_a(\pi\, mc^2 kT)^{-\frac{1}{2}} \exp[-(E'-mc^2)^2/(kT\, mc^2)]\} \times (4/0.15), \qquad (6)$$

where the observed photon energy, E, and the emitted energy E′ are related by $E' = (1+z)E$ with $z = 0.26$. The first term, $F_s(E)$, is from eq. (4) with $\gamma_o = 7$, $B = 10^{11}$ gauss, $d\gamma/dt = 0.5\ (d\gamma/dt)_s$ and $F_a = 250$ photons/cm^{2}sec. The second term assumes a gaussian form for the annihilation feature, justified by the small fraction of annihilations in flight. The width of the feature is determined by kT, which, as discussed above, reflects the balance between synchrotron loss and Comptonization. The curve of Figure 1 is based on kT = 0.075 MeV. (We note that a pair density of 2.5×10^{26} cm^{-3} is well below the degeneracy limit at this temperature). The factor 4 sec/0.15 sec transforms the 4 sec measurements of Mazets et al. (1979) into the expected flux density during the 0.15 sec impulsive phase, under the assumption that the contribution of the pulsed phase during the first 0.15 seconds is small.

As can be seen from Figure 1, the solid curve does provide a reasonable fit to the data, in particular in view of the many uncertainties of the problem and the extreme complexity of the physical system under consideration. The excess flux density at the high energy end of the spectrum could be due to those hot photons that are not stopped in the transition layer, while the excess at the low energies could be the contribution of the pulsed phase.

IV. Summary and Conclusions

We have provided what amounts to a mostly qualitative discussion for the origin of the March 5, 1979 transient. We take at face value the identification with the supernova remnant N49 in the Large Magellanic Cloud, and we assume that the burst is produced by a catastrophic event within a neutron star such as a phase transition in its interior. This should lead to the release of a large amount of gravitational energy which, nonetheless, would still be much smaller that the binding energy of the star. The transport of this energy to the surface is an unsolved problem, although it appears that neutron star vibrations are a viable possibility: they could not only provide a readily available, coherent form of energy storage, but also heat the atmosphere mechanically to the MeV temperatures that are necessary to provide both the high efficiency of the radiation mechanism and the e^+-e^- pairs that seem to be responsible for the $\sim$ 0.4 MeV spectral feature. Decay of these vibrations by gravitational radiation could explain the duration ($\sim$ 0.15 sec) of the impulsive phase of the burst.

The radiation mechanism is extremely efficient in that it produces a very high luminosity in relatively low energy photons, and this appears to violate the black body limit. We overcome the difficulty by assuming that the radiation is nonthermal emission from high energy ($\sim$ MeV) pairs, but that these pairs are cooled by a strong magnetic field before they annihilate. The observed spectrum, therefore, is a combination of synchrotron and annihilation radiations. The magnetic field may have, in addition, another very important role: it could help to confine the ambient atmosphere of the star from being blown away by the super-Eddingtonian luminosity of the impulsive phase.

We have provided no treatment of the pulsed phase or of the subsequent outbursts on March 6, April 4 and April 24. The pulsed phase could be due to black body radiation at kT $\sim$ 30 keV from the polar caps of the star, and the subsequent events could be smaller aftershocks of the initial event. But we defer any further discussion of these problems to future papers.

Acknowledgements

We wish to acknowledge very useful discussions with S. Bonazzola, J. Felten, A. Harding, F. Jones, D. Kazanas, B. Kozlovsky, D. Leiter, P. Meszaros, T. Northrop and B. Teegarden on various issues treated in this paper. R. R. wishes to acknowledge in particular his discussions with Tom Cline, whose strong and persistent belief (based on the data) that the source of the March 5 transient is in the LMC rather than in some nearby object, probably was the strongest motivation for the developmnet of the ideas presented in this paper. The research of R.E.L. was supported by NSF Grant AST 79-11987 and that of R. W. B. by NASA Grant NGR 21-002-316.

Figure Caption

Energy spectrum of the March 5 transient during the first 4 seconds (Mazets et al. 1979). The curve is the calculated spectrum resulting from the sychrotron cooling and subsequent annihilation of e^+-e^- pairs injected with initial kinetic energy of 3 MeV into a strong but disordered magnetic field of 10^{11} gauss. The pair temperature after cooling is 0.075 MeV.

References

Aharonian, F. A. and Ozernoy, L. M.: 1979, Astronomitcheskii Tsizkulyar, No, 1072, p. 1, September 17, 1979.

Barat, S., Chambon, G., Hurley, K., Niel, M., Vedrenne, G., Estulin, I. V., Kurt, V. G. and Zenchenko, V. M.: 1979, Astron. and Astrophys. 79, L24.

Bussard, R. W., Ramaty, R., and Drachman, R. J.: 1979, Astrophys. J. 228, 928.

Cavallo, G. and Rees, M. J.: 1978, Mon. Not. R. Astr. Soc. 183, 359.

Chupp, E. L., Forrest, D. J., Higbie, P. R., Suri, A. N., Tsai, C. and Dunphy, P. P.: 1973, Nature 241, 333.

Cline, T. L.: 1980, Comments on Astrophysics (in press).

Cline, T. L., Desai, U. D., Pizzichini, G., Teegarden, B. J., Evans, W. D., Klebesadel, R. W., Laros, J. G., Hurley, K., Niel, M., Vedrenne, G., Estulin, I. V., Kouznetsov, A. V., Zenchenko, V. M., Hovestadt, D. and Gloeckler, G.: 1980, Astrophys. J. Lett. (in press).

Detweiler, S. L.: 1975, Astrophys. J. 197, 203.

Evans, W. D., Klebesadel, R. W., Laros, J. G., Cline, T. L., Desai, U. D., Pizzichini, G., Teegarden, B. J., Hurley, K., Niel, M., Vedrenne, G., Estoulin, I. V., Kouznetsov, A. V., and Zenchenko, V. M.: 1979, Astrophys. J. Lett. (in press).

Ginzburg, V. L. and Syrovatskii, S. I.: 1964, Origin of Cosmic Rays (Pergamon, NY).

Hartle, J. B., Sawyer, R. F., and Scalapino, D. J.: 1975, Astrophys. J. 199, 471.

Helfand, D. J. and Long, K. S.: 1979, Nature, 282, 589.

Hudson, H. S., Bai, T., Gruber, D. E., Matteson, J. L., Nolan, T. L., and Peterson, L. E.: 1980, Astrophys. J. Lett. 236, L91.

Hurley, K.: 1980, Cospar Proceedings, in press.

Jacobson, A. S., Ling, J. C., Mahoney, W. A. and Willett, J. B.: 1978, Gamma Ray Spectroscopy in Astrophysics (eds. Cline, T. L. and Ramaty, R.) p. 228 (NASA TM 79619).

Landau, L. D. and Lifshitz, E. M.: 1958 Statistical Physics (Pergamon Press, London).

Leventhal, M., MacCallum, C. J. and Stang, P. D.: 1978, Astrophys. J. Lett. 225, L11.

Lingenfelter, R. E., Higdon, J. C. and Ramaty, R.: 1978, Gamma Ray Spectroscopy in Astrophysics (eds. Cline, T. L. and Ramaty, R.) p. 252 (NASA TM79619).

Mazets, E. P. and Golenetskii, S. V.: 1979, A. F. Ioffe Physico-Technical Institute, preprint 632.

Mazets, E. P., Golenetskii, S. V., Il'inskii, V. N., Aptekar', R. L. and Guryan, Yu. A.: 1979, Nature 282, 587.

Petschek, A. G. and Colvin, J. D.: 1980 (to be published).

Ramaty, R., Kozlovsky, B. and Lingenfelter, R. E.: 1979, Astrophys. J. Suppl. 40, 487.

Ramaty, R. and Lingenfelter, R. E.: 1979, Nature 278, 127.

Ruderman, M.: 1975, Annals N.Y. Acad. Sci. 262, 164.

Schmidt, W. K. H.: 1978, Nature, 271, 525.

Shapiro, S. L. and Salpeter, E. E.: 1975, Astrophys. J. 198, 671.

Teegarden, B. J. and Cline, T. L.: 1980, Astrophys. J. Lett. (in press).

Thorne, K. S.: 1969, Astrophys. J. 158, 1.

Vedrenne, G.: 1980, Cospar Proceedings, in press.

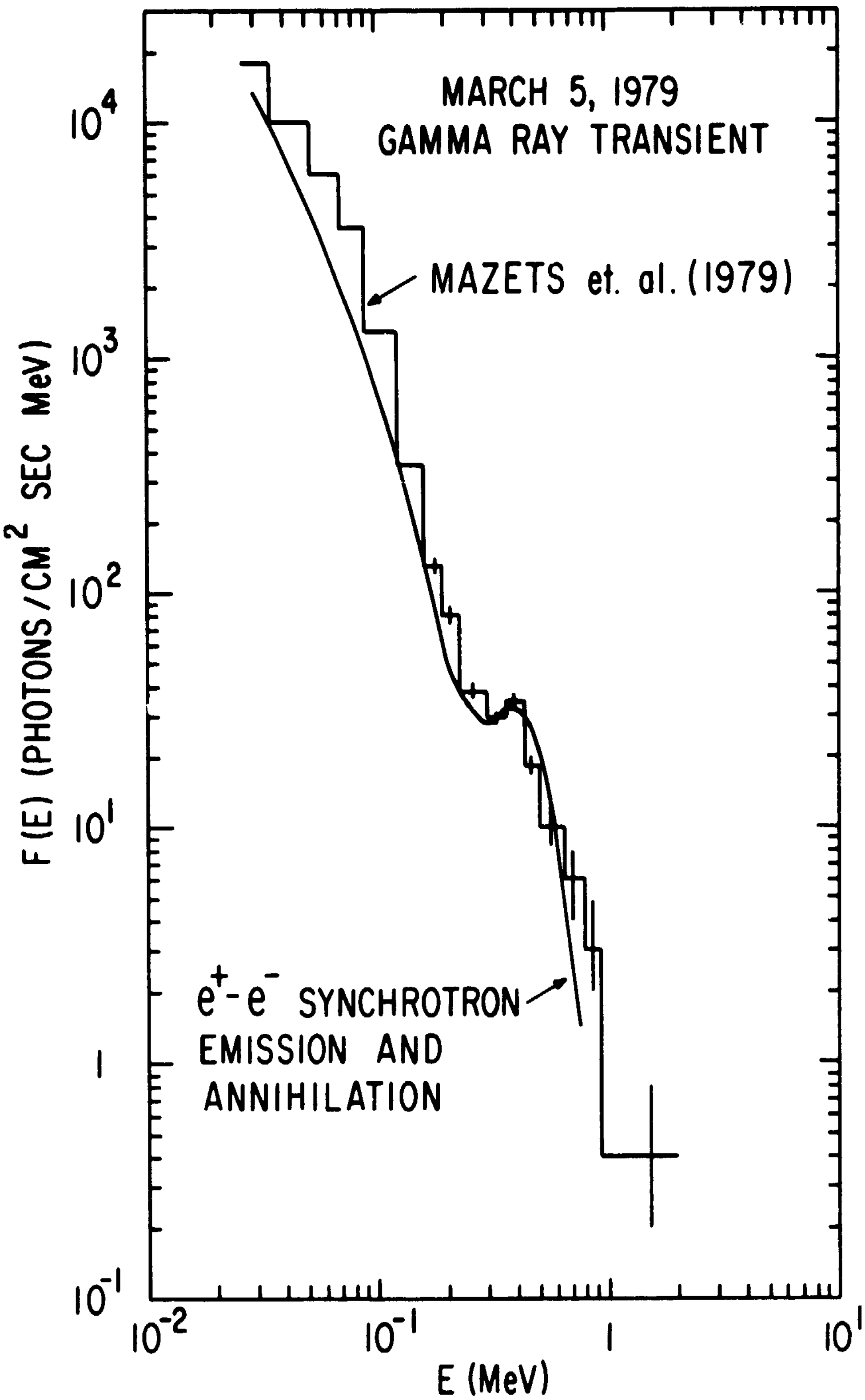

Fig. 1

ORIGINAL PAGE IS
OF POOR QUALITY

BIBLIOGRAPHIC DATA SHEET

1. Report No. TM 80674	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Synchrotron Cooling and Annihilation of an e^+-e^- Plasma: The Radiation Mechanism for the March 5, 1979 Transient		5. Report Date March 1980
		6. Performing Organization Code
7. Author(s) R. Ramaty and R. E. Lingenfelter		8. Performing Organization Report No. 660
9. Performing Organization Name and Address Laboratory for High Energy Astrophysics Theoretical Group Code 660		10. Work Unit No.
		11. Contract or Grant No.
		13. Type of Report and Period Covered TM
12. Sponsoring Agency Name and Address		
		14. Sponsoring Agency Code

15. Supplementary Notes

To be published in the Proceedings of the Toulouse Symposium and Workshop on Cosmic Gamma Ray Bursts. Astrophysics and Space Science

16. Abstract

Positron-electron pair radiation is examined as a mechanism that could be responsible for the impulsive phase emission of the March 5, 1979 transient. Synchrotron cooling and subsequent annihilation of the pairs can account for the energy spectrum, the very high brightness, and the ~ 0.4 MeV eature observed from this transient, whose source is likely to be a neutron star in the supernova remnant N49 in the Large Magellanic Cloud. In this model, the observed radiation is produced in the skin layer of a hot, radiation-dominated pair atmosphere, probably confined to the vicinity of the neutron star by a strong magnetic field. The width of this layer is only about 0.1m. In this layer, $\sim 10^{12}$ generations of pairs are formed (by photon-photon collisions), cooled and annihilated during the $\sim$ -.15 sec duration of the impulsive phase. The very large burst energy implied by the distance of the LMC, and its very rapid release, are unsolved problems. We mention, nonetheless, the possibility of neutron star vibrations, which could transport the energy coherently to the surface, heat the atmosphere mechanically to a hot, pair-producing temperature, and have a characteristic damping time roughly equal to the duration of the impulsive phase.

17. Key Words (Selected by Author(s)) neutron star vibrations, synchrotron radiation, electron positron annihilation, gamma ray transients	18. Distribution Statement

19. Security Classif. (of this report) UN	20. Security Classif. (of this page) UN	21. No. of Pages 21	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22151.

GSFC 25-44 (10/77)